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The Diagnostic Utility of Behavioral Checklists in Identifying Children with ADHD and Children with Working Memory Deficits

Authors: TracyPackiam Alloway · SusanE. Gathercole · Joni Holmes · Maurice Place · JulianG. Elliott · Kerry Hilton

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Abstract	The present study investigated whether children with ADHD and those with working memory impairments have a common behavioral profile in the classroom. Three teacher checklists were used: the Conners' teacher rating scale (CTRS), the behavior rating inventory of executive function (BRIEF), and the working memory rating scale. The Conners' continuous performance test (CPT) was also included to determine whether there is a correspondence between performance on this widely used cognitive measure of attention deficits and teacher ratings of classroom behavior. All three behavior scales, but not the CPT, were able to successfully discriminate children with ADHD and those with working memory deficits from typically-developing children. Both the CTRS and the BRIEF discriminated a significant proportion of the children with ADHD from those with working memory deficits, indicating that while both groups exhibit behavioral problems in the classroom, they are characterized by differential attention profiles. The children with ADHD were identified on the basis of oppositional and hyperactive behavior, while those with working memory deficits were more inattentive.

Keywords (separated by '-')	ADHD - Attention - Working memory - Continuous performance test - Behavior rating scales
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ARTICLE

The Diagnostic Utility of Behavioral Checklists in Identifying Children with ADHD and Children with Working Memory Deficits

Tracy Packiam Alloway · Susan E. Gathercole · Joni Holmes · Maurice Place · Julian G. Elliott · Kerry Hilton

Abstract The present study investigated whether children with ADHD and those with working memory impairments have a common behavioral profile in the classroom. Three teacher checklists were used: the Conners' teacher rating scale (CTRS), the behavior rating inventory of executive function (BRIEF), and the working memory rating scale. The Conners' continuous performance test (CPT) was also included to determine whether there is a correspondence between performance on this widely used cognitive measure of attention deficits and teacher ratings of classroom behavior. All three behavior scales, but not the CPT, were able to successfully discriminate children with ADHD and those with working memory deficits from typically-developing children. Both the CTRS and the BRIEF discriminated a significant proportion of the children with ADHD from those with working memory deficits, indicating that while both groups exhibit behavioral problems in the classroom, they are characterized by differential attention profiles. The children with ADHD were identified on the basis of oppositional and hyperactive behavior, while those with working memory deficits were more inattentive.

Keywords ADHD · Attention · Working memory · Continuous performance test · Behavior rating scales

Introduction

The core features leading to a diagnosis of attention-deficit/hyperactivity disorder (ADHD) are significant levels of over-activity, inattention, and impulsiveness [1]. Children with

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ADHD are usually seen as having great difficulty remaining seated when required to, and being much more active than their peers. They also find it hard to remember complex instructions, show poor attention to instructions, and find it hard not to interrupt with their comments. These symptoms can vary depending on the situation, which makes the diagnosis quite challenging at times, but the use of formal rating scales does give some objectivity to the assessment [2]. The ADHD assessment considers biological, psychological, and social factors, because children with ADHD usually show significant social, academic, and psychological difficulties at each stage of their development [3].

The worldwide prevalence of ADHD is estimated to be 5% [4], though in the UK research suggests a lower rate of 1–3% [5, 6]. In clinics, far more boys present with the disorder than girls, possibly because girls have lower ratings of externalizing problems than boys [7]. Within community samples, the gender ratio is approximately 3:1 [8]. The presence of ADHD increases the risk of the child having oppositional defiance and conduct disorder considerably [9], and it has a strong tendency to persist into adulthood [10]. There is also a considerable increase in the risk of substance misuse [11], as well as other psychiatric disorders such as anxiety and depression [9].

According to Barkley [12], behavioral inhibition is a central impairment in those with ADHD (though see the motivational deficits theory [13]). A key feature of Barkley's model is that inhibition serves as a trigger for secondary effects in various executive functions, including working memory [14, 15]. Working memory is a system of interacting cognitive components that support the storage and mental manipulation of information over brief periods of time [16]. Although working memory shares a neuroanatomical association with the frontal lobes, current evidence suggests that in cognitive terms at least, it is distinct from other executive functions such as inhibition [17]. Individuals with ADHD exhibit substantial working memory deficits, particularly in visuo-spatial tasks [18, 19]. In contrast, performance in short-term memory tasks, such as forward recall of digits, words, and spatial locations, tends to be within age-expected levels [20].

The aim of the present study was to investigate whether behavioral inhibition in those with ADHD would serve as a trigger for working memory problems [21], as evidenced by classroom behavior profiles. This research question has diagnostic utility for educators, who are increasingly involved in the initial detection of children with attention problems. Behavioral rating scales are common instruments used in evaluating attention and executive function problems [22], and teacher questionnaires such as the Conners' teacher rating scale (CTRS) [23] and the behavior rating inventory of executive function (BRIEF) [24] measure a constellation of behaviors typical of this profile [25]. In addition to these scales, we also included the working memory rating scale (WMRS) [26], a validated teacher checklist to identify behaviors associated with working memory impairments, in the present study. The use of different teacher ratings allowed us to examine the relationship between behaviors pertaining to attention and working memory in children with ADHD.

One concern about the use of teacher checklists is the degree to which such evaluations are open to a negative halo effect where some behaviors have greater impact upon teacher evaluations than others. For example, disruptive behaviors such as defiance towards a teacher are more likely to result in the child being rated as both hyperactive and inattentive, despite there being an absence of attention problems on their part [27, 28]. In order to provide external validity for the teacher ratings, performance on a direct measure of sustained attention, the Conners' continuous performance test (CPT) [29] was also included in the study. This test, which involves the child monitoring the appearance of an occasional target among more frequent non-target events over a lengthy period of time is

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the performance measure that is widely used as part of the clinical assessment for ADHD, with affected children showing elevated levels of incorrect detection of non-target events [30].

Of additional interest was whether children with ADHD would have distinguishable classroom behavior profiles those selected specifically on the basis of working memory deficits but not attention problems. The limited capacity of working memory varies widely between individuals, and is closely associated with learning abilities during childhood [31]. Recent evidence suggests that children with working memory deficits represent a distinct group from those with ADHD. First, those working memory difficulties have a pervasive deficit that impacts both verbal and visuo-spatial working memory, rather than a selective impairment of either verbal or visuo-spatial difficulties. This pervasive deficit is associated with low learning outcomes [32] and without appropriate intervention, these students lag behind their peers [33].

Second, their behavioral profile is distinct from those with a clinical diagnosis of ADHD [32, 34]. Relatively few of the children were judged to exhibit the high levels of hyperactive and impulsive behaviors that are found in the majority of children with a clinical diagnosis of ADHD. Instead, teachers rated these children as highly inattentive, with poor attention spans and high levels of distractibility. They were also commonly described as forgetting what they are currently doing and things they had learned, as well as failing to remember instructions and complete tasks.

We tested the following hypotheses in the present study. If behavioral inhibition in children with ADHD impacts working memory functioning beyond a cognitive level, then we would expect them to also exhibit behaviors associated with working memory problems. For the children with low working memory, their behavior profile should be motivated by working memory deficits rather than inhibition difficulties. As a result, they would have a distinct classroom behavior profile from those with ADHD. The present study also allowed us to investigate which teacher rating scales are better at discriminating those with attention and memory problems from typically-developing children, as well as the correspondence between performance on teacher ratings of classroom behavior and the CPT.

Methods

Participants

The participating schools represent a range of demographics, indexed by the national average of eligibility for free school meals, a poverty (income) index used in the UK. Three groups of children participated in the study. The ADHD group comprised 46 children (40 boys; mean age = 9.75 years, SD = 12 months) with a combination of hyperactive-impulsive and inattentive behavior (ADHD-combined). Diagnosis of ADHD subtype was confirmed by a comprehensive clinical diagnostic assessment by pediatric psychiatrists and community pediatricians based in the UK. The assessments were based on scores in the deficit range on the continuous performance test [29] and clinical assessments during interview sessions using the DSM-IV criteria [1] and the CHEDOC. The study only included children who score in the normal range on the Developmental, Diagnostic and Dimensional Interview (3di), a computerized assessment for autistic spectrum disorders [35]. All children were receiving stimulants for ADHD (e.g., methylphenidate).

A healthy comparison group and a group of children with low working memory were selected from a sample of ~1,000 children, aged 8–11 years, who were screened on two

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tests of verbal working memory (listening recall and backwards digit recall subtests of the AWMA [36]. These children were screened as part of a larger study reported in Holmes et al. [18]. Children with standard scores below 86 on both tests (bottom 15th centile) were assigned to the low working memory group, and those with standard scores in the normal range (>90 on both tests) formed a comparison group. Children in both the comparison and low working memory groups were age-matched to within 60 days (±30 days) of children in the ADHD group. The working memory-impaired (WM-I) group consisted of 25 children (15 boys; mean age = 9.91 years, SD = 11 months) identified via screening as having standard scores below 86 on both the listening recall and backwards digit recall tests from the automated working memory assessment [36]. The typically developing (TD) children ($n = 20$) consisted of 11 boys (mean age = 9. 91 years, SD = 11 months). While there were a greater number of boys than girls in the ADHD group, reflecting the higher rate of diagnosis among boys, this gender bias was not evident in the comparison or low working memory groups.

Materials

Continuous Performance Test

The *K* test of the continuous performance test (CPT) [29] was administered to assess the children's performance on a vigilance task. In this version of the CPT, a series of letters appears on the computer screen. The child is required to press the space bar in response to the letter *K*, but must not respond when any other letter appears. In total, 480 stimuli are presented for 250 ms, with an inter-stimulus interval of 1 s. The target stimuli appear on 140 of the trials at random intervals. The number of omissions and commissions as counts are reported here.

Teacher Rating Scales

Teachers completed three rating scales for all participating children. The Conners' teacher rating scale-revised, short form (CRS-R) [23] is designed to identify attentional failures and ADHD on the basis of classroom behaviors. In this test, teachers are asked to rate the extent to which the child has had problem behaviors in school over the past month that are described in 28 brief statements on the form. The response choices for each described behavior are: not true at all, just a little true, pretty much true, and very much true. Responses are scored as sums of values on four subscales—oppositional (e.g., spiteful or vindictive), cognitive problems/inattention (e.g., forgets things s/he has already learned), hyperactivity (e.g., is always "on the go" or acts as if driven by a motor), and ADHD index (e.g., restless, always up and on the go). The ADHD Index is based on the best set of items for identifying children at risk of a diagnosis of ADHD. *T*-scores (with a population mean of 50 and SD of 10) are calculated for each of the four subscales. Test–retest reliability coefficients for subscale scores reported for a sample of 50 children with a mean age of 11 years were as follows: oppositional (.62), cognitive problems/inattention (.73), hyperactivity (.85), and ADHD Index (.72).

The behavior rating inventory of executive function (BRIEF) [24] assesses problem behaviors associated with executive function in school. The form consists of 86 brief descriptions of behavior problems, the frequency of which teachers are asked to rate as occurring either never, sometimes, or often. Responses are aggregated to form eight subscales. The inhibit scale measures the ability to control impulses, and to stop own

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behavior at the proper time. The shift scale assesses the ability to move freely from one situation, activity, or aspect of a problem to another as the situation demands; it also taps behaviors relating to transition, and to the ability to solve problems in a flexible manner. The emotional control scale relates to the ability to modulate emotional responses appropriately. The initiate scale measures the ability to begin a task or activity, and to generate ideas independently. The working memory scale assesses the ability to hold information in mind for the purpose of completing an activity. The plan/organize scale assesses abilities to anticipate future events, set goals, develop appropriate steps ahead of time, carry out tasks in a systematic manner, and to understand and communicate main idea. The organization of materials scale relates to abilities to maintain relevant parts of the environment in an orderly manner. The monitor scale relates to abilities to check work, assess performance, and to keep track of own and others' efforts. Examples of test items from each subscale are shown in the Appendix. *T*-scores are calculated for each measure. Test–retest correlations for individual subscale score reported for a sample of 41 children were: inhibit (.91), shift (.83), emotional control (.92), initiate (.87), working memory (.87), plan/organize (.88), organization of materials (.83), and monitor (.87).

The Working Memory Rating Scale (WMRS) [26] consists of 20 descriptions of behaviors characteristic of children with working memory deficits. Examples include: 'The child raised his hand but when called upon, he had forgotten his response'; 'She lost her place in a task with multiple steps'; and 'The child had difficulty remaining on task'. Teachers rate how typical each behavior was of a particular child, using a four-point scale ranging from (0) *not typical at all* to (1) *occasionally* to (2) *fairly typical* to (3) *very typical*. Cronbach's alpha across the normative sample was .978, establishing internal reliability of the scale [37].

Procedure

All were tested on a one-to-one basis as part of the main study and no child/parent declined participation. All children with ADHD were taken off their medication 24 h prior to testing and the CPT was administered as part of a larger cognitive test battery [18].

Results

Group Profiles

For all three behavior scales, *T*-scores, with a population mean of 50 and SD of 10, were calculated (Table 1). As a guide, scores of 55 or below do not represent a cause for concern, while scores above 60 can be viewed in terms of increasing risk of impairment (see Conners, 2001). On the CTRS, mean scores in the ADHD group were elevated for the all four subscales. In contrast, only the score in the cognitive problems/inattention score ($M = 64$) was high for the WM-impaired group. On the BRIEF, mean scores on all subscales were more than 1 SD above the mean (>60) for the ADHD group. The WM-impaired group scored within age-expected levels for most of the subscales; exceptions include the working memory, initiate, and monitor subscales (Ms = 64, 61, and 63, respectively). In the WMRS, the mean scores for the ADHD and WM-impaired groups were above expected levels (Ms = 60 and 58, respectively). The TD group scored within the expected range on all measures.

Table 1 Descriptive statistics for CPT and behavior measures as a function of group

Measures	Groups											Pairwise comparisons					
	ADHD			WM-impaired			TD			Group comparison		ADHD and TD		WM-I and TD		ADHD and WM-I	
	n	*M*	SD	*n*	*M*	SD	*n*	*M*	SD	*p*	η_p^2	*p*	*d*	*p*	*d*	*p*	*d*
CPT: omissions	46	36.39	28.33	25	30.68	25.11	20	36.45	24.19	0.66	0.01	0.99	0.00	0.77	0.23	0.69	0.21
CPT: commissions	46	87.96	78.40	25	78.88	75.71	20	77.35	76.72	0.83	0.01	0.88	0.14	0.98	0.02	0.90	0.12
CTRS																	
Oppositional	46	64.63	14.73	25	56.48	13.17	20	49.95	9.75	0.00	0.17	0.00	1.18	0.32	0.56	0.05	0.58
Cognitive problems/inattention	46	61.39	11.66	25	63.96	11.47	20	45.40	4.59	0.00	0.32	0.00	1.80	0.00	2.13	0.98	0.22
Hyperactivity	46	61.98	12.13	25	54.12	12.26	20	45.90	4.00	0.00	0.26	0.00	1.78	0.04	0.90	0.02	0.65
ADHD index	46	63.07	14.50	25	57.84	13.73	20	46.40	6.60	0.00	0.21	0.00	1.48	0.01	1.06	0.33	0.37
BRIEF																	
Inhibit	46	70.26	16.05	25	58.88	18.07	20	46.58	6.24	0.00	0.29	0.00	1.36	0.02	0.81	0.00	0.65
Shift	46	65.43	15.95	25	55.44	13.63	20	49.26	6.33	0.00	0.20	0.00	1.04	0.32	0.55	0.01	0.64
Emotional control	46	70.48	19.72	25	59.00	19.74	20	50.16	9.35	0.00	0.18	0.00	1.05	0.22	0.54	0.03	0.57
Behavior regulation index	46	71.77	16.83	25	58.56	18.16	20	48.35	7.20	0.00	0.27	0.00	1.81	0.10	0.74	0.01	0.76
Working memory	46	68.00	15.34	25	63.52	17.15	20	48.47	7.40	0.00	0.22	0.00	1.24	0.00	0.98	0.43	0.29
Plan/organize	46	66.50	12.47	25	57.92	12.91	20	47.11	7.97	0.00	0.29	0.00	1.39	0.02	0.90	0.01	0.66
Initiate	46	65.28	11.89	25	61.16	15.99	20	46.63	7.75	0.00	0.26	0.00	1.39	0.00	1.00	0.38	0.31
Organization of materials	46	61.59	13.31	25	56.64	16.85	20	47.79	6.68	0.00	0.15	0.00	1.04	0.07	0.64	0.30	0.34
Monitor	46	69.83	12.13	25	62.88	19.42	20	47.00	8.80	0.00	0.29	0.00	1.49	0.00	0.93	0.12	0.45
Metacognition index	46	68.09	13.21	25	60.92	16.18	20	47.55	7.96	0.00	0.29	0.00	1.88	0.00	1.05	0.08	0.49
Global executive index	46	70.70	14.78	25	62.04	18.90	20	49.85	12.89	0.00	0.22	0.00	1.50	0.04	0.75	0.09	0.51
WMRS	31	60.13	9.36	17	57.71	11.97	10	44.40	4.17	0.00	0.22	0.00	2.17	0.00	1.49	0.66	0.23

Note: Behavior measures are represented as *T*-scores are shown in the table ($M = 50$, SD = 10); not all WMRS forms were returned

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A series of MANOVAs were performed on the *T*-scores for the subscales of the CTRS and the BRIEF. The probability value associated with Hotelling's *t*-test and Cohen's *d* effect size values are reported in Table 1. On the CTRS, the ADHD group had significantly higher scores (i.e., worse performance) in all subscales compared with the TD group, and in the oppositional and hyperactivity subscales compared to the WM-impaired group. The WM-impaired group also had significantly higher scores in all subscales compared to the TD group. In the BRIEF, the ADHD group was rated more highly in all subscales compared to the TD group, and in the inhibit, shift, emotional control, and plan/organize subscales compared to the WM-impaired group. The ratings for the WM-impaired group differed significantly from the TD group in all subscales, except for the shift and emotional control subscales. In the WMRS, both the ADHD and WM-impaired groups were rated significantly higher than the TD group. A MANOVA was also performed on the omission or commission errors in the CPT and the probability value associated with Hotelling's *t*-test and Cohen's *d* effect size values are reported in Table 1.

In order to compare the severity of behavioral profiles across the groups, *T*-scores were banded according to categories as identified by the BRIEF to allow for direct comparison between the behavioral measures (Table 2). As there is no discrete point at which typical and atypical performance can be unequivocally distinguished, cumulative proportions over a range of values that represent different degrees of severity of low performance are

Table 2 Cumulative proportions of children obtaining *T*-scores for the behavioral measures in each band as a function of age group and subscale

	ADHD					WM-impaired					Control				
Measure	*n*	<46	<56	<66	>65	*n*	<46	<56	<66	>65	*n*	<46	<56	<66	>65
CTRS															
Oppositional	46	.17	.35	.48	.52	25	.28	.60	.76	.24	20	.45	.85	.90	.10
Cognitive problems/ inattention	46	.13	.33	.59	.41	25	.08	.20	.52	.48	20	.65	.95	1.0	0
Hyperactive	46	.09	.33	.67	.33	25	.20	.72	.80	.20	20	.60	.90	1.0	0
ADHD index	46	.11	.30	.57	.43	25	.12	.56	.76	.24	20	.65	.95	.95	.05
BRIEF															
Inhibit	46	.04	.16	.33	.67	25	.28	.64	.68	.32	20	.67	.86	.95	.05
Shift	46	.08	.33	.56	.44	25	.28	.68	.80	.20	20	.38	.86	.95	.05
Emotional control	46	.08	.27	.41	.59	25	.28	.68	.80	.36	20	.38	.81	.86	.14
Behavior regulation index	46	.06	.19	.38	.62	25	.20	.64	.72	.58	20	.55	.85	.95	.05
Initiate	46	.04	.22	.47	.53	25	.16	.44	.60	.72	20	.62	.91	.95	.05
Working memory	46	.08	.22	.38	.62	25	.16	.40	.56	.79	20	.48	.81	1.0	0
Plan/organize	46	.06	.20	.43	.57	25	.12	.64	.76	.24	20	.67	.86	.95	.05
Organization of materials	46	.09	.40	.57	.43	25	.20	.60	.76	.24	20	.50	.85	1.0	0
Monitor	46	0	.14	.33	.67	25	.08	.56	.64	.36	20	.48	.81	.95	.05
Metacognition index	46	.04	.21	.43	.57	25	.12	.52	.68	.32	20	.60	.85	.95	.05
Global executive composite	46	.04	.15	.39	.61	25	.08	.15	.39	.61	20	.55	.85	.90	.10
Working memory rating scale	30	.13	.29	.74	.26	17	.24	.53	.71	.29	10	.60	1.0	0	0

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presented. For scores that are moderately atypical (>65), more than half the ADHD group achieved this level in the oppositional subscale of the CTRS; and all subscales of the BRIEF (except for the shift and organization of materials subscales).

In contrast, almost half of the WM-impaired group (48%) obtained high ratings on the cognitive problems/inattention subscale, which included the following behaviors: greater academic difficulties compared to their peers, difficulty organising and completing tasks, and trouble concentrating on activities that require mental effort. Fewer children (20%) showed signs of restlessness and fidgetiness that are characteristic of hyperactive behavior. There was a similar pattern for the BRIEF subscales: over 50% of the WM-impaired group had *T*-scores greater than 65 in the behavior regulation index, and the initiate and working memory subscales. The latter two are related to the child's ability to plan and effectively manage information in working memory. This finding indicates that children with working memory deficits struggled with classroom activities that relate to working memory such as organizing large amounts of information and monitoring work to avoid errors. However, they did not exhibit the difficulties in controlling behavior or emotion that characterized the children with ADHD.

Correlations

Correlations coefficients among the CPT scores and behavior measures for the ADHD group are displayed in the lower triangle in Table 3; and those for the WM-impaired group are shown in the upper triangle. For the ADHD group, only the CPT omission rates were significantly associated with some of the BRIEF subscales (initiate, working memory, plan/organize, monitor, metacognition index, and global executive composite) and the WMRS (*r*s ranged from .35 to .43). CPT scores were not significantly linked with the behavior regulation index subscales or the CTRS. The intercorrelations between the CTRS and the BRIEF subscales were moderate to high, with *r*s ranging from .38 to .74; with the exception of the cognitive problems/inattention subscale and the shift subscale from the BRIEF. The CTRS and the BRIEF subscales related to attention and working memory skills (working memory, plan/organize, and monitor subscales) were significantly related to the WMRS ratings, with *r*s ranging from .42 to .81.

For the WM-impaired group, the correlations between the CPT scores and behavioral measures indicate that only the commissions error rates were significantly associated with the shift subscale from the BRIEF ($r = 47$). The CTRS subscales were significantly associated with all the BRIEF subscales, with the exception of the oppositional subscale and the Shift and Initiate BRIEF subscales (*r*s ranged from .72 to .94). Both the CTRS and the BRIEF were significantly linked to the WMRS, with the exception of the Oppositional subscale (*r*s ranged from .63 to .92). The moderate to high coefficients suggest good concurrent validity between the different teacher checklists purportedly measuring attention and working memory in the classroom.

Group Membership

In order to determine which behavior ratings uniquely differentiated the groups, discriminant function analyses were conducted for CPT scores and indices from each behavior measure (Table 4). Looking first at data for the ADHD and WM-impaired groups compared with the TD group, CPT omission and commission scores were not an effective discriminator of either ADHD or working memory impairment. In contrast, all three behavior scales were able to successfully discriminate the ADHD and WM-impaired

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Table 3 Correlations between the CPT and behavior measures for the ADHD-combined group in lower triangle; and for the WM-impaired group in upper triangle

Measures	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
CPT: omissions	–	−.01	−.20	−.02	−.26	−.26	−.24	−.10	−.26	−.23	−.24	−.21	−.01	−.24	−.25	−.19	−.24	.01
CPT: commissions	.01	–	−.04	.16	.19	.26	.10	.47	.07	.20	.29	.20	.16	.20	.23	.12	.33	.41
CTRS: cppositional	−.09	.07	–	.23	.59	.49	.61	.39	.70	.63	.36	.48	.63	.53	.52	.55	.53	.11
CTRS: cognitive problems/inattention	−.07	−.11	.45	–	.57	.64	.60	.49	.34	.52	.85	.74	.68	.62	.73	.76	.73	.83
CTRS: hyperactivity	−.09	.21	.70	.52	–	.91	.93	.79	.84	.92	.77	.86	.85	.88	.90	.90	.96	.73
CTRS: ADHD index	−.08	.19	.56	.50	.76	–	.87	.75	.71	.84	.79	.85	.83	.78	.86	.85	.94	.81
BRIEF-inhibit	−.14	.14	.69	.47	.71	.63	–	.80	.87	.97	.73	.88	.86	.90	.84	.90	.92	.70
BRIEF-shift	−.26	.12	.58	.26	.38	.43	.57	–	.74	.89	.60	.73	.83	.73	.66	.69	.83	.63
BRIEF-emotional control	−.05	.11	.72	.37	.58	.52	.79	.80	–	.94	.52	.69	.77	.71	.67	.72	.75	.43
BRIEF-behavioral regulation index	−.20	.14	.74	.38	.63	.56	.87	.86	.95	–	.67	.83	.88	.84	.79	.83	.90	.63
BRIEF-initiate	−.39	−.22	.55	.65	.46	.47	.63	.57	.55	.65	–	.88	.72	.77	.85	.88	.87	.90
BRIEF-working memory	−.38	−.08	.52	.67	.63	.63	.75	.53	.58	.69	.85	–	.81	.89	.90	.97	.91	.93
BRIEF-plan/organize	−.43	−.12	.55	.55	.59	.51	.65	.61	.59	.68	.85	.82	–	.79	.76	.84	.87	.76
BRIEF-organization of materials	−.25	−.09	.50	.60	.62	.59	.67	.44	.57	.61	.66	.77	.71	–	.84	.92	.89	.75
BRIEF-monitor	−.38	.04	.58	.58	.62	.54	.80	.56	.70	.75	.69	.82	.75	.76	–	.94	.91	.79
BRIEF-metacognition index	−.41	−.12	.58	.66	.63	.58	.78	.60	.66	.75	.89	.94	.92	.85	.89	–		.92
BRIEF-global executive composite	−.35	0	.70	.60	.69	.62	.88	.75	.82	.90	.85	.89	.87	.77	.89	.95	–	.82
Working memory rating scale	−.36	−.11	.53	.74	.61	.42	.64	.32	.51	.56	.81	.74	.77	.47	.75	.76	.72	–

Note: For the ADHD group, coefficients between .35 and .37 are significant at the .05 level and >.37 are significant at the .01 level; for the WM-impaired group, coefficients between .48 and .51 are significant at the .05 level and >.51 are significant at the .01 level

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Table 4 Classification by discriminant function analysis for CPT and behavior measures

Variable entered	Correctly classified as			Correctly classified as			Correctly classified as		
	WL (*df*)	ADHD	TD group	WL (*df*)	WM-I	TD group	WL (*df*)	ADHD	WM-I
CPT	.99 (2)	19 (41%)	13 (65%)	.99 (2)	17 (68%)	8 (40%)	.99 (2)	23 (50%)	16 (64%)
CTRS ADHD index[a]	.73 (1)*	33 (72%)	19 (95%)	.79 (1)*	12 (48%)	17 (85%)	.90 (2)*	29 (63%)	20 (80%)
BRIEF: all 3 indices[b]	.57 (3)*	36 (78%)	18 (90%)	.78 (3)*	13 (52%)	16 (84%)	.87 (2)*	31 (67%)	19 (76%)
WMRS	.55 (1)*	22 (82%)	10 (100%)	.69 (1)*	11 (65%)	9 (90%)	.98 (1)	17 (63%)	9 (53%)

Note: WL = Wilks Lambda; * $p<.03$

For comparisons between the ADHD and WM-I groups

[a] Oppositional and hyperactive subscales only

[b] Behavior regulation index and plan/organize subscale only

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groups from the TD group. The CTRS ADHD index was sufficient to correctly assign group membership for 72% of the ADHD and 48% of the WM-impaired groups. This figure rose to 78% for the ADHD group for the BRIEF indices, and to 82 and 65% ADHD and WM-impaired groups, respectively for the WMRS. This outcome establishes that all behavior measures could successfully discriminate these groups from TD group, with the WMRS correctly classifying identifying the greatest proportion.

In order to evaluate the extent to which the behavior measures may differentiate the ADHD group from the WM-impaired group, only the oppositional and hyperactive subscales from the CTRS and the behavior regulation index and plan/organize subscale from the BRIEF were included as the groups differed significantly on these scores. Both the CTRS and the BRIEF identified a significant proportion of the children correctly: 63 and 67%, respectively for the ADHD group; and 80 and 76%, respectively for the WM-impaired group. However, the WMRS did not discriminate significantly between these groups, which suggest that both groups displayed behaviors associated with working memory because both groups have working memory problems.

Discussion

The aim of the present study was to investigate whether behavioral inhibition in those with ADHD would serve as a trigger for working memory problems, as evidenced by classroom behavior profiles. Teacher ratings in the present study had good diagnostic validity, with high levels of classification accuracy of the three groups. While all three behavior scales were able to successfully discriminate the ADHD and WM-impaired groups from the TD group, the WMRS identified the greatest proportion in each group, although it was not able to discriminate between children in the ADHD and WM-impaired groups. This suggests that both these atypical groups display common classroom behaviors associated with working memory difficulties. Both the CTRS and the BRIEF discriminated a significant proportion of the ADHD from the WM-impaired group, indicating that while both groups exhibit behavioral problems in the classroom, they are characterized by differential attention profiles. The children with ADHD were rated more highly in oppositional and hyperactive behaviors (CTRS), as well as with inhibiting, shifting and controlling emotions (BRIEF), while the WM-impaired children were best characterized by behaviors related to working memory difficulties, including planning and organizing information.

The nature of the relationship between the CTRS, BRIEF, and WMRS teacher ratings is also of interest in the present study. While the close association between these three checklists provides support for the concurrent validity of these measures, the pattern of correlations suggests that they each measure distinct behavioral components. For example, the CTRS assesses oppositional and hyperactive behaviors not included in the other two rating scales, while the BRIEF evaluates shifting, planning, and organizing skills. Given that the ADHD-combined subtype encompasses heterogeneous behavioral manifestations, it seems useful to administer more than one teacher checklist in order to detect attention problems in the classroom.

On the CPT test, the children with ADHD made significantly more errors of commission than either the control children or the WM-impaired group. However, CPT scores were not significantly associated with the CTRS ratings, nor were they able to successfully discriminate the ADHD and WM-impaired groups from the TD group. It is not uncommon for children to score in the clinical range on some teacher checklists, yet perform successfully on the CPT [25]. Despite the positive predictive power of the CPT to measure sustained

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attention, low correlations between these scores and behavior ratings by teachers have been reported before [38]. While omission scores are linked to attention in the classroom, between 30–50% of clinically-diagnosed children with ADHD are not detected by CPT performance [39]. The CPT also appears to lack diagnostic specificity to ADHD relative to other clinical conditions [40]. One possible explanation is that the CPT measures vigilance, rather than attention per se. There are other confounding factors as the CPT requires rapid identification of letters and is highly associated with phonological awareness, identifying those with reading disorders that may not have a clinical diagnosis of ADHD [41]. The present findings suggest that while the CPT can be informative, it may be best to include other complementary assessments of attention.

There are limitations to this study that should be addressed in future research. The study would benefit by larger-scale research recruiting the inattentive subtype. This is of particular value in the UK as the inattentive subtype is seldom represented in clinical services. These children do not exhibit troublesome behaviors in the classroom so are not referred through the usual route. One possibility is that children with working memory deficits are in fact those with the inattentive subtype as their behavioral characteristics appear to be very similar. Further research comparing these two groups would clarify this issue. The sample size was admittedly uneven. While reported effect sizes indicate a modest difference across groups, replication with a larger sample would provide a better test of potential differences in behavioral profiles. The gender bias in the present study is in line with reported higher male to female ratios, usually 4–1 [42]. Previous research on the male-female ratio in clinical referrals of ADHD highlights more boys identified for the hyperactive/impulsive subtype, while more females are categorized as the inattentive subtype [43]. It would be of interest to explore whether teachers detect such gender biases in classroom behavior.

The present findings have important implications given the link between attention and working memory. Pupils with ADHD are more likely to achieve lower grades at school than their peers although it is inattentiveness, rather than impulsivity, that is problematic in this respect [44]. This pattern is also evident in those who exhibit ADHD symptoms but have not received a formal diagnosis of the disorder [45]. Working memory problems negatively impact performance in classroom activities such as remembering lengthy instructions, keeping track of their place in multi-level tasks, and coping with the simultaneous processing and storage demands frequently imposed in structured learning activities [46, 47].

Summary

Behavioral inhibition in children with ADHD appears to impact working memory functioning in the classroom as well. Working memory deficits are implicated in ADHD, although may not be necessary for ADHD nor specific to it. Children with low working memory have a distinct classroom behavior profile from those with ADHD as they do not exhibit behaviors associated with hyperactivity or impulsivity. As both problems with memory and attention are linked with learning, checklists that successfully identify children with problems in these areas are useful for clinical and educational practitioners.

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